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January 1984

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FINAL REPORT

to

U.S. AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
Bldg. 410, Bolling Air Force Base
Washington, D.C.   20332

Contract No. F49620-82-K-0020

INTERFACIAL CHEMICAL REACTIONS AND TRANSPORT PHENOMENA IN FLOW SYSTEMS

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Period Covered: 1 December 1981 – 30 November 1983

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INTERFACIAL CHEMICAL REACTIONS AND TRANSPORT PHENOMENA IN FLOW SYSTEMS
F49620-82K-0020

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TABLES

ABBREVIATIONS

BL	boundary layer	PI	Principal Investigator
CT	combustion turbine	QS	quasi-steady
LBL	laminar boundary layer	SCC	surface catalyzed combustion
MIPES	microwave-induced plasma emission spectroscopy	TBL	turbulent boundary layer

1. INTRODUCTION, OBJECTIVES

Diffusion rates of reactants, reaction intermediates, reaction products and impurites determine the performance of combustion systems -- even systems that are premixed and/or turbulent. The existence of large temperature gradients, particularly in laminar (sub-) regions, gives rise to an appreciable thermal diffusion contribution to the "species" mass flux (called Soret-diffusion for vapors, or thermophoresis for particulate matter). This final report reviews, among other things, our recent experimental and theoretical developments on the consequences of thermal diffusion mass transfer in combustion systems, with present emphasis on the behavior of hydrogen in surface-catalyzed-combustion (SCC) and condensate particles (e.g., ash, soot) in a local temperature gradient. In terms of molecular weight disparity (between the transported species and prevailing "carrier" gas) these examples represent important limiting cases, with high molecular weight (e.g., fuel-) vapor transport falling in between.

As will be summarized in Sections 2.1 and 2.2, in this research program we have demonstrated several important effects of temperature gradients on diffusional mass transport rates in combustion systems. In general, light vapor species tend to drift toward hot regions/surfaces, and heavy species/particles tend to drift toward cold regions/surfaces. The latter effect is particularly strong, and should also produce some dramatic consequences for small particle nucleation, growth, migration, coagulation and burnout in flames. It is hoped that this research stimulates increased attention to these often neglected phenomena, and their practical consequences in combustion systems. Moreover, our mass transfer research, suitably extended and tested, can be expected to: a) open possibilities for the incorporation of deposition rate criteria in the design/optimization of next-generation salt/ash-"tolerant" turbines; b) enable the establishment of sharper minimum performance specifications for all "upstream" fuel treatment, combustion and ash separation systems; and c) suggest rational simulation criteria for laboratory testing of CT blades/materials.

The purpose of this final report is to briefly summarize our research methods and accomplishments under AFOSR Contract F 49620-82K-0020 (Technical Monitors: B.T. Wolfson and J.M. Tishkoff) during the two-year period: 12/1/81 - 11/30/83. Readers interested in greater detail than that contained in Section 2 are advised to consult the published papers cited in Section 2, and listed in Section 3.1. Copies of any of these published papers or preprints listed in Section 3.1 can be obtained by writing the PI: Prof. Daniel E. Rosner at the Department of Chemical Engineering, Yale University, Box 2159 Y.S., New Haven, CT, 06520, U.S.A. Comments on, or examples of, the applicability of our research results will be especially welcome.

2. RESEARCH ACCOMPLISHMENTS

2.1 Surface-Catalyzed Combustion of Hydrogen

Appreciable effects of Soret (thermal diffusion) transport for hydrogen/air combustion have been predicted for premixed laminar flame structure, and reported in the Russian literature (on surface-catalyzed combustion (SCC)). Our recent SCC-investigations[13], carried out using isothermal calorimetric (power-balance) techniques in the subatmospheric Pt-ribbon reactor shown in Fig. 2.1-1, reveal that the rate of H_2 transport to an

H_2 SURFACE COMBUSTION EXP.

YALE UNIVERSITY

NOZZLE ASSEMBLY

$p = 0.09$ atm.

Pt FOIL
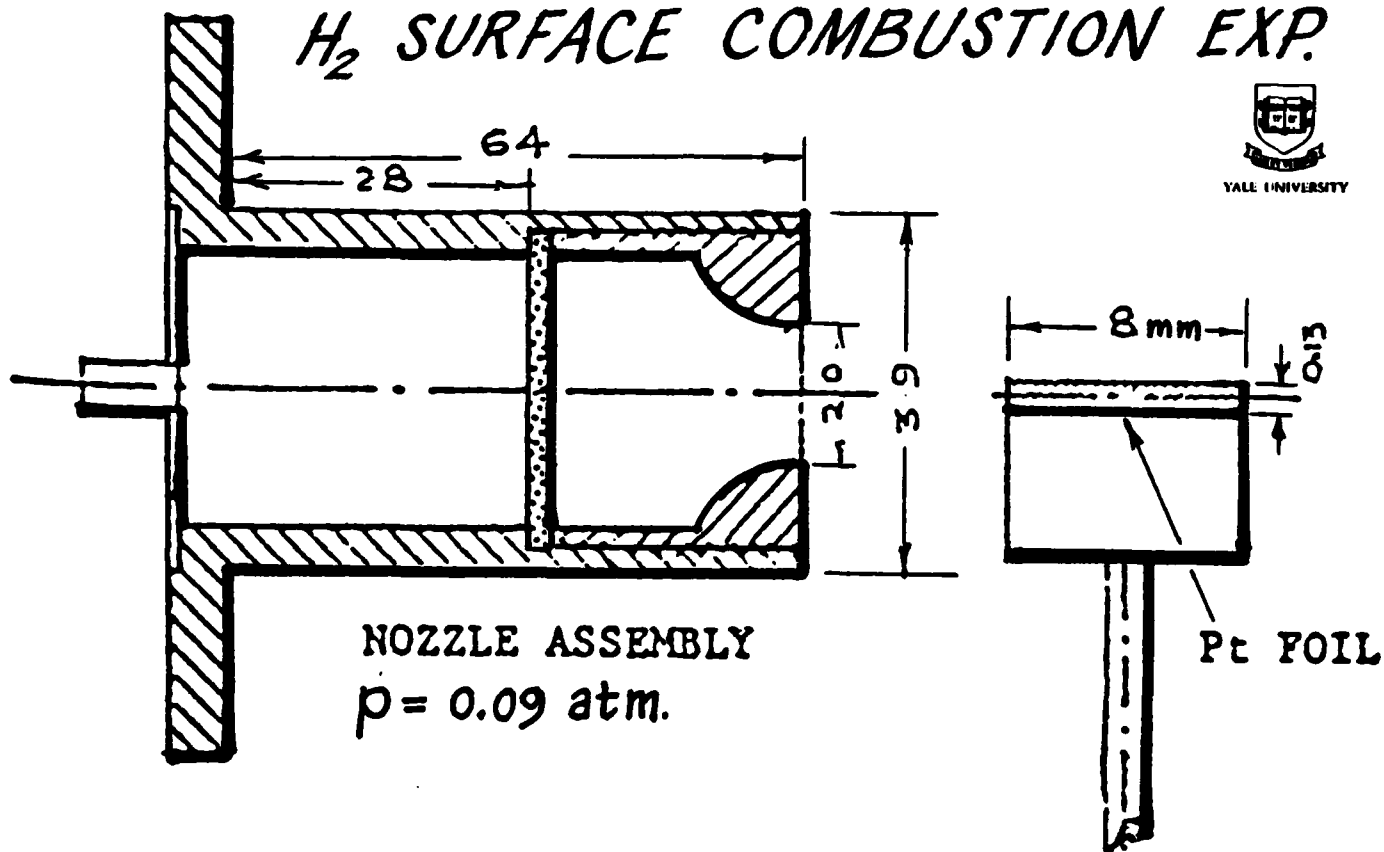
2.1-1 Detail (schematic) of subatmospheric Pt-ribbon flow reactor for
calorimetric studies of surface-catalyzed combustion[13]; reactant
gas temperature, Tg, near 300K.

active, hot catalytic surface (e.g., Pt, with $T_w/T_g \approx 3-4$) is systematically increased by more than ten percent (Fig. 2.1-2) by the prevailing temperature gradients. Still larger modifications of vapor **mass** transport can be expected for H-atoms, or in cases where heavy organic fuel vapors are transported[13].

2.2 Transport of Combustion-Generated Particulate Matter

2.2.1 Seeded Flame Experiments on Submicron Particulate Transport Rates[2,11]

Small **particle** transport through nonisothermal gases can easily be **dominated** by thermophoresis, as was confirmed in our recent optical experiments[2] on submicron MgO-particle deposition from (MgSO$_4$-seeded) propane/air flames (Fig. 2.2-1). Relative deposition rates, measured on-line **via** the loss in Pt-target reflectivity, were obtained at various target and gas temperatures (Fig. 2.2-2) and found to agree with the predictions of thermophoretic LBL theory[3,4] (cf. solid curve, Fig. 2.2-2). Moreover, for the same seed level, particle deposition rates at $T_w/T_g \approx 0.7$ were estimated to be over 1000-times larger than the corresponding rate of convective- (Brownian-) diffusion (T_w/T_g-insensitive (dashed curve), Fig. 2.2-2). These experiments are now being extended to include **soot** deposition from fuel-rich premixed flat flames. Preliminary evidence (Section 2.2.2) indicates that soot particle transport to targets or thermocouples is described by the abovementioned laws of particle thermophoresis, although the thermophoretic coefficient of such non-spherical particle aggregates remains to be measured and predicted.

2.2.2 Preliminary Soot Deposition Rate Experiments Using Thermocouple Response Techniques in Rich Hydrocarbon/Air Flat Flames[1]

Using transient size and temperature measurements obtained on a small thermocouple bead suddenly immersed in the soot-laden combustion products downstream of a water-cooled flat-flame burner, we have recently[1] demonstrated (**via** suitable straight line plots (Fig. 2.2-3)) that **soot** deposition rates are also dominated by particle **thermophoresis, i.e.,** soot particle drift down the temperature gradient prevailing in the gas thermal boundary layer (BL) surrounding the thermocouple target. Observed soot deposition mass fluxes were estimated to be about 100-times greated than those that would have been expected on the basis of only Brownian (concentration) diffusion at the prevailing Reynolds numbers. We concluded that: a) the dependence of the soot deposition rate on temperature "contrast" is in approximate accord with recently proposed thermophoretic BL theories[3,4]; and b) the behavior of submicron soot particles in nonisothermal combustion products is strongly influenced by thermophoresis, with important implications for soot coagulation, burnout and deposition.

In new soot deposition experiments, initiated during the second year of this program but not yet brought to fruition, we are using laser light scattering techniques to make real-time measurements of soot deposition rates on an actively-cooled stagnation-flow target.

2.2.3 Theoretical Studies of Boundary Layer Transport of Combustion-Generated Particulate Matter

In support of the deposition rate experiments described in Sections 2.1 and 2.2, rigorous boundary layer calculations, including the non-Fickian mass
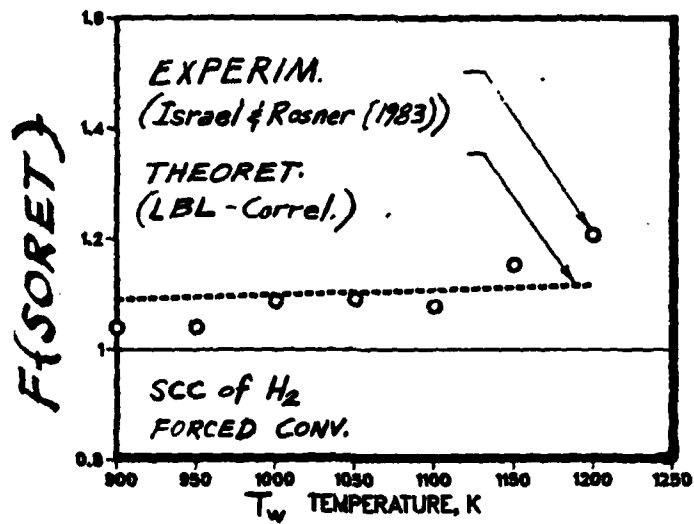
2.1-2: Thermal diffusion (Soret-effect) enhancement
        of the H_2 transport rate to a Pt-catalyst
        surface[13]; comparison of experiment with
        theory[13,17].
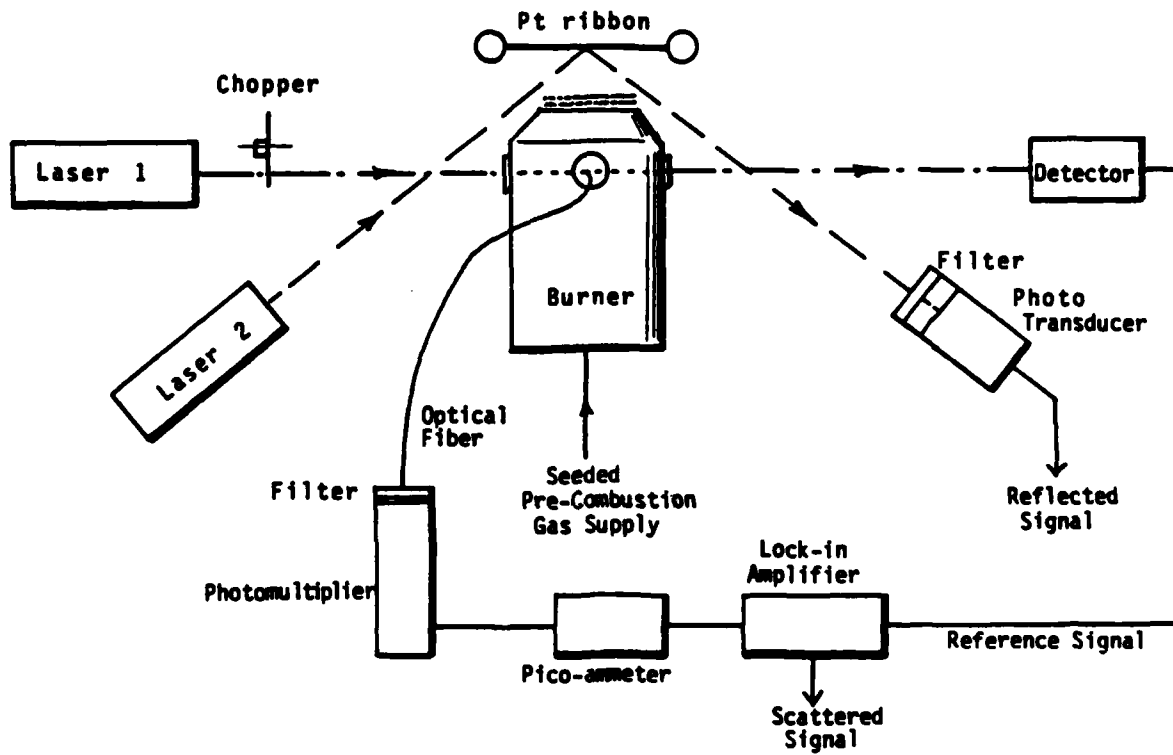
2.2-1: Schematic of experimental arrangement for real-time optical
reflectivity studies of submicron particle deposition rates
from seeded laboratory flat flames[2,11].
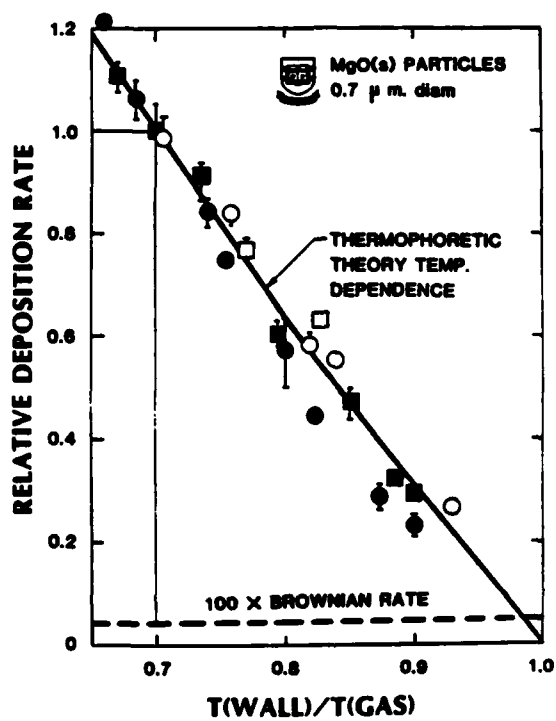
2.2-2: Comparison of pooled MgO particle deposition rate data (normalized to $T_w/T_g=0.7$) with the T_w/T_g-dependence predicted by thermophoresis-augmented boundary layer theory ($\bigcirc$T(gas)=1500K, ■T(gas)=1560K, ●T(gas)=1578K, □T(gas)=1585K).

SOOT DEPOSITION ON TC BEAD

PRELIM TEST OF THERMOPHORETIC

BL THEORY
(using $d(t)$ via $T(t)$-record)

x-axis: $\left(\dfrac{T_g - T}{T}\right) \cdot \left(\dfrac{T}{T_g}\right)^{(a_t \cdot Le)^{0.76}}$

y-axis: $10^5 \, \dot{r}_w ; \dfrac{dd_w}{dt}$ via TC-OUTPUT
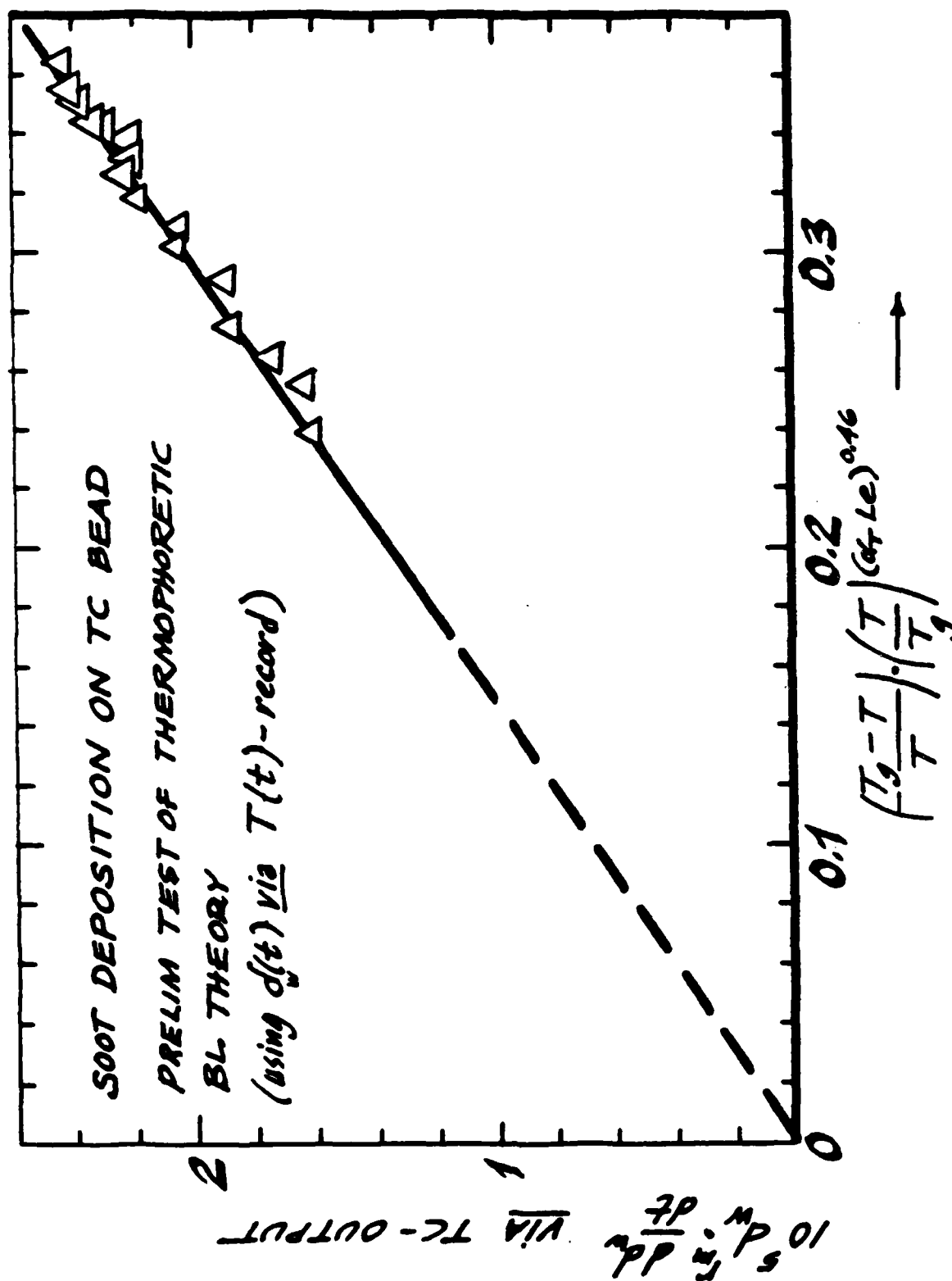
2.2-3: Indirect test of thermophoretically controlled soot deposition rate mechanism; straight line plot based only on thermocouple output, $T(t)$, exploiting the constant emittanc: QS energy balance[1] to infer the instantaneous bead diameter, $d_w(t)$. (See Ref. 1 for details of procedure, notation.)

transfer mechanism of thermal diffusion ("thermophoresis"), have been carried
out, and the results used to develop and test simple engineering correlations.
As representative outcome of our particle mass transport theoretical studies,
Fig. 2.2-4, shows one test of our recently developed correlation[4] for rapidly
predicting thermophoretically augmented small particle mass transport rates
across laminar or turbulent[15,16] nonisothermal boundary layers, including
effects of transpiration cooling, and viscous dissipation. Plotted is the
ratio of actual mass transfer coefficient (Stanton number) to the
corresponding coefficient without particle thermophoresis. Note that, as
indeed observed in our experiments (Sections 2.2.1, 2.2.2), temperature
gradients can augment the rate of particle capture by over 1000-fold, and our
correlation covers a 4-decade range. Over 100 rigorously computed "data"
points are shown, with our simple, rational correlation exhibiting an average
error of less than 8% in the important parameter range: $0.5 \leq T_w/T_g \leq 1.0$, $0 \leq$
Mach No. $\leq$, $10 \leq$ Schmidt No. $\leq 10^6$. This research is currently being extended
to include: thermophoretically augmented transport of non-spherical aerosol
particles (e.g., soot aggregates); implications for both practical combustor
deposition and particle sampling from laboratory combustors; effects of
advanced surface cooling techniques[7,8] (film and transpiration) on deposition
from extreme temperature "dusty" gases; and deposition on surfaces which are
hotter than the ambient, particle-laden gas stream.

In closely related theoretical developments, new methods for correlating
and extending available inertial impaction information have been
developed[5,6,12], and can be used to simplify calculations of combustor and
turbine fouling in the presence of compressible gas flow, non-Stokes particle
drag and inevitable geometric complexity.

For intermediate size particles the abovementioned diffusional and
inertial mechanisms "interact" -- indeed, inertial effects can influence
diffusional deposition in the absence of actual inertial impaction[14]. A
rational conceptual approach to the treatment of such interactions, based on
the notion of inertially modified particle concentrations at the mass transfer
BL edge, has been developed and illustrated. These results should simplify
the problem of accurately predicting the spatial distribution of deposition
over a range of intermediate (ca. 1 μm diam.) particle sizes.

Finally, we remark that a portion of our theoretical effort has been
devoted to the dynamics of liquid condensate flows on collector surfaces[9]. As
a result, aerodynamic shear-driven laminar liquid layers on combustion turbine
surfaces can now be predicted. In our current work this theory has been
extended to include the simultaneous effects of surface rotation, and the
dissolution/corrosion rate consequences of such condensate layer flows on
nonisothermal surfaces. It is interesting to note that this work should also
apply to thin liquid fuel layers on downstream flame-holders, and at the base
of transverse fuel jet injectors.

2.3 Heterogeneous Chemical Kinetics

2.3.1 Chemical and Physical Energy Accommodation at Catalytic Surfaces[10,18]

In our previous AFOSR-sponsored research program, to gain a better
understanding of the molecular level events which dictate catalyst surface
temperatures, we carried out calorimetric measurements on simple heterogeneous
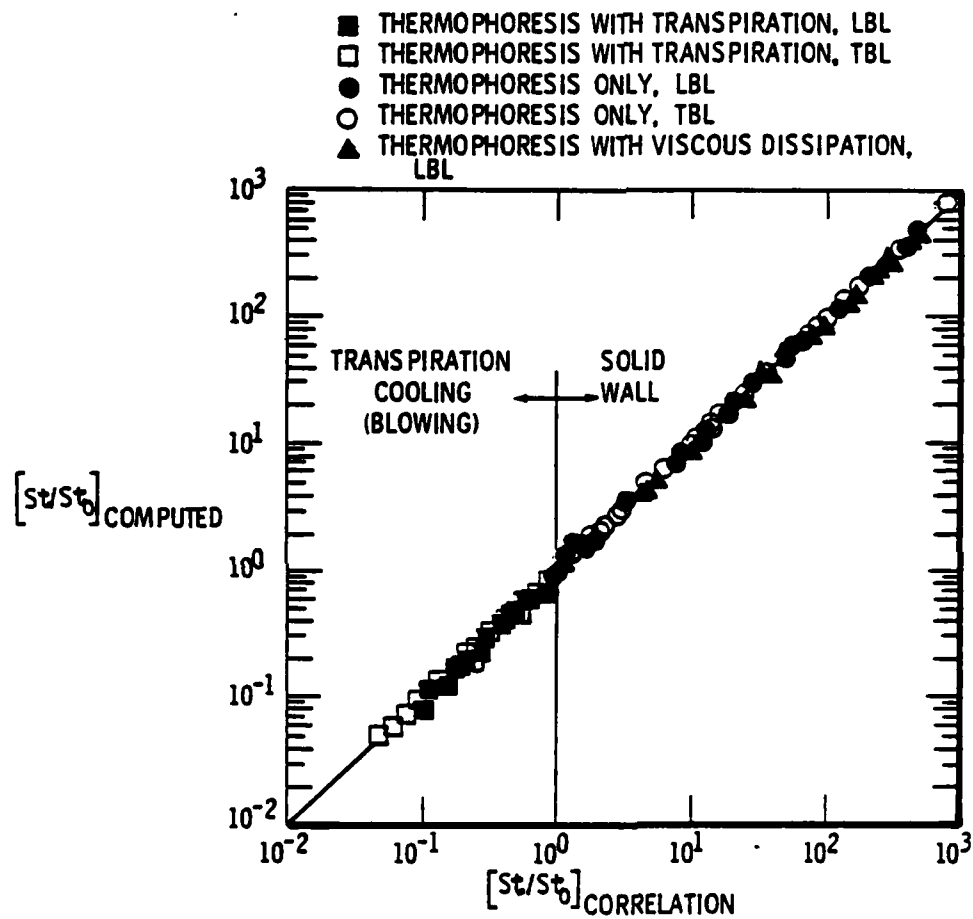
2.2-4: Accuracy of correlations for small particle transport across
gaseous boundary layers in the presence of thermophoresis,
viscous dissipation and transpiration cooling[4].

reactions, with emphasis on surface-catalyzed $N_2H_4(g)$ decomposition. These measurements have now been completed and documented for publication in J. Phys. Chem.[10]. A review article outlining the atmospheric chemistry implications of our findings has also been published in Amer. Geophys. Union Monograph No. 2: Heterogeneous Atmospheric Chemistry (1982). Reviewing briefly the contents of Ref. 10, energy transfer to the catalyst per reaction event was studied for hydrazine vapor decomposing on Pt, Ir, or W at T > 900°K. The measurements utilized a newly developed fast-flow chemical reactor which can yield, in a single experiment, values of the chemical energy accommodation coefficient β, thermal accommodation coefficient α for unreacted hydrazine, and the reaction probability γ. Due to the relatively small reaction exoergicity (< 1 ev/molec.) and the great difference between the temperatures of the incident gas and catalyst surface, under the present experimental conditions the reaction becomes endoergic at the catalyst temperature T = 1520°K. We found that above that temperature products depart in thermal equilibrium with the catalyst but below it product molecules carry off 30-40% of the prevailing exoergicity. This result was explained by the desorption of translationally hot H_2 product molecules. Incidently, direct desorption of H-atoms contributes to the catalyst energy loss in the case of W above 2000°K.

2.3.2 Development and Application of Microwave-Induced Plasma Emission Spectroscopy (MIPES)

We have recently developed an emission spectroscopic technique which facilitates (i) instantaneous gas/solid reaction rate measurements over a large temperature range in a single experimental run, and (ii) surface mass balances which are necessary for mechanistic understanding of high temperature gas/solid reactions. In this technique, a low-pressure microwave-induced plasma (MIP) excites characteristic emission from the atoms in the gaseous product species of the gas/metal reaction in a low pressure flow reactor. It should be noted, that, while MIP systems have received much attention as spectrochemical excitation sources in the past, this work is evidently the first to make use of the analytical capabilities of MIPs to study the kinetics of high-temperature gas/solid reactions.

We employ a modified version of the transonic, vacuum flow reactors (Fig. 2.3-1) developed earlier under AFOSR-support for the study of gas/solid reactions by Rosner and co-workers[20-22]. However, now the reaction product vapor species are dissociated and electronic emission from the resulting atoms is produced in a second microwave discharge plasma (G) before leaving the reactor. Evaporation and gasification reactions are studied by measuring emission intensity from this discharge, via a quartz window, a 75mm-focal-length condensing lens and a 0.5m Jarrell-Ash monochromator.

Aside from steady-state reaction rate measurements, flash evolution experiments can be carried out to measure the amount of condensed product material formed on a surface during reaction provided, of course, that the reaction product has a higher volatility than that of the substrate. In such experiments the filament is exposed to the gaseous reagent for some reaction time (normally only a few minutes). Then, the gaseous reagent flow into the reactor is stopped and the filament cooled to near 300K. Finally, the I(t) is determined when the filament is heated rapidly. The skimmer and the inner co-axial tube shown in Fig. 2.3-1 were installed so that the system detects only products from the central, uniform-temperature region of the filament. Valves
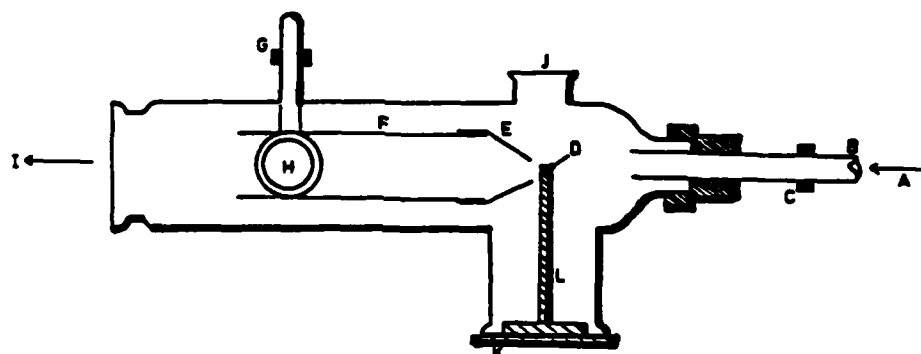
A, reactant and inert gas mixture;
B, alumina tube; C, microwave cavity; D, electrically heated specimen
filament; E, aluminum skimmer; F, pyrex annular tube; G, microwave cavity;
H, quartz observation window; I, to pump, manometer, and throttle valve;
J, pyrometer sight tube; K, specimen probe; L, electrical leads and
voltage taps to measure specimen resistance.

2.3-1: Transonic flow reactor for kinetic studies of gas/solid
(filament) surface reactions using the method of micro-
wave-induced plasma emission spectroscopy (MIPES)[19].

are provided to divert the gaseous reagent to the reactor exhaust or to allow it to pass through the reactor during such "flash evolution" experiments.

While exploratory flash evolution experiments are now being carried out for the F(g)/Pt(s) system we first demonstrated the capability of MIPES to rapidly and quantitatively follow low metal fluxes by examining the sublimation rate of platinum, using the 304.2 nm line of the Pt(g)-emission spectrum. Figure 2.3-2 reveals that over more than a 2-decade range of metal atom fluxes (starting at only about 2×10^{13} atoms/cm^{2}sec) the Pt emission intensity and Pt-flux are directly proportional to one another, as required to exploit MIPES for future gas/solid kinetic studies. Of special interest will be the application of this MIPES-technique to the oxidation of <u>boron</u>, a system of considerable interest to the propulsion community but one whose poorly understood kinetics are apparently influenced by the condensibility of the reaction product B$_2$O$_3$*.

3. COMMUNICATION OF RESEARCH RESULTS

3.1 <u>Papers Submitted, Published</u>

P1. Eisner, A.D. and Rosner, D.E., "Soot Particle Thermophoresis in Non-Isothermal Combustion Gases," <u>20th Symposium (Int.) on Combustion</u> (submitted, January, 1984).

P2. Rosner, D.E. and Kim, S.S., "Optical Experiments on Thermophoretically Augmented Sub-Micron Particle Deposition Rates from `Dusty´ High Temperature Gas Flows," <u>Chem. Engrg. J.</u> (in press, 1984).

P3. Gokoglu, S.A. and Rosner, D.E., "Thermophoretically-Augmented Forced Convection Mass Transfer Rates to Solid Walls Across Non-Isothermal Laminar Boundary Layers," <u>AIAA J.</u> (submitted, 1983).

P4. Gokoglu, S.A. and Rosner, D.E., Int. J. Heat and Mass Transfer <u>27</u>, 639-645 (1984).

P5. Rosner, D.E., Gokoglu, S.A. and Israel, R., in <u>Fouling of Heat Exchanger Surfaces</u>, Engineering Foundation, NY (R. Bryers, ed.), 235-256 (1983).

P6. Rosner, D.E. and Fernandez de la Mora, J., "Discussion of Boundary Layer Effects on Particle Impaction and Capture," ASME Trans.-<u>J. Fluids Engrg.</u> (in press, 1984).

P7. Gokoglu, S.A. and Rosner, D.E., Int. J. Heat and Fluid Flow <u>5</u>, No. 1, 37-41 (1984).

P8. Gokoglu, S.A. and Rosner, D.E., "Thermophoretically Enhanced Mass Transport Rates to Solid and Transpiration-Cooled Walls Across Turbulent (Law-of-the-Wall) Boundary Layers," <u>Ind. Engrg. Chem./Fundamentals</u> (in press, 1984).

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* This system has some features in common with the O,N/Si(s) system we studied under AFOSR-support[23] in 1968-1969. That paper[23] proved useful in the design of the NASA Space Shuttle Orbiter Vehicle leading edge system.
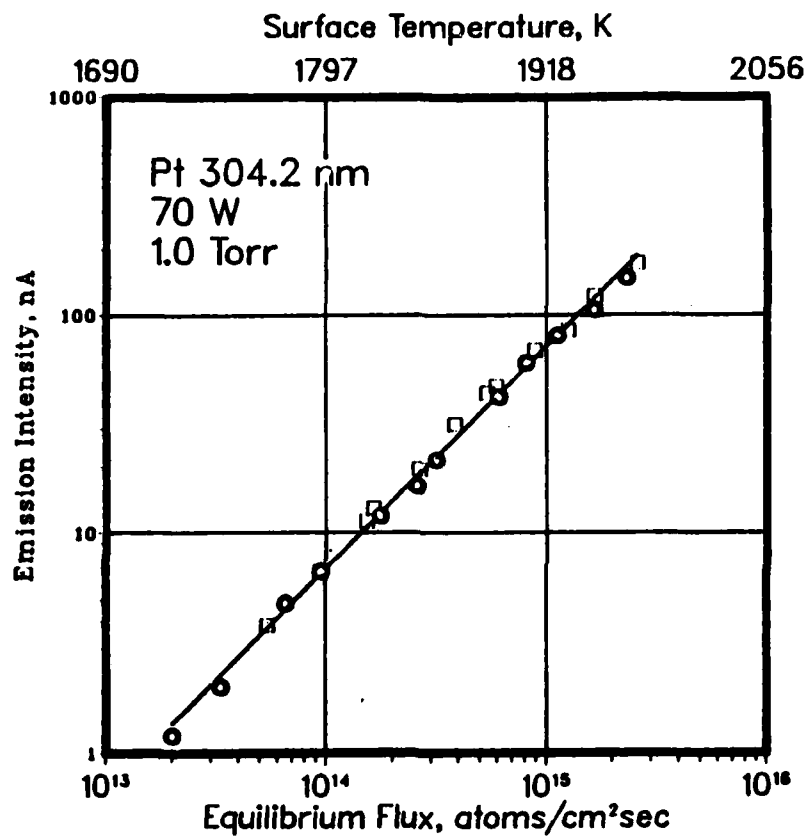
2.3-2: Microwave-induced Pt emission line intensity, I,
in filament wake vs. equilibrium Pt flux for
steady-state Pt(s) sublimation[19].

P9. Rosner, D.E., Gunes, D. and Nazih-Anous, N., Chem. Engrg. Communications 24, 275-287 (1983).

P10. Kiela, J.B., Halpern, B.L. and Rosner, D.E., "Chemical and Physical Energy Accommodation in the Metal Surface-Catalyzed Decomposition of Hydrazine Vapor," J. Phys. Chem. (in press, 1984).

P11. Rosner, D.E. and Atkins, R.M., in Fouling and Slagging Resulting from Impurities in Combustion Gases, Engineering Foundation, NY (R. Bryers, ed.), 469-492 (1983).

P12. Israel, R. and Rosner, D.E., Aerosol Sci. and Technology 2, 45-51 (1983).

P13. Israel, R., Thermal Diffusion Effects on Fuel Vapor Mass Transport Across Non-Isothermal Boundary Layers in Surface-Catalyzed Combustion, Ph.D. Dissertation, Yale Univ., Chemical Engrg. Dept. (1983).

P14. Fernandez de la Mora, J. and Rosner, D.E., J. Fluid Mechanics 125, 379-395 (1982).

P15. Rosner, D.E. and Fernandez de la Mora, J., ASME Trans-J. Engrg. for Power 104, 885-894 (1982).

P16. Rosner, D.E. and Fernandez de la Mora, J., in Particulate Laden Flows in Turbomachinery (W. Tabakoff, C.T. Crowe and D.B. Cale, eds.) ASME, NY, 85-94 (1982).

P17. Gokoglu, S.A., Thermophoretically Enhanced Deposition of Particulate Matter Across Nonisothermal Boundary Layers, Ph.D. Dissertation, Yale Univ., Chem. Engrg. Dept. (1982).

P18. Halpern, B. and Rosner, D.E., in Geophysical Monograph No. 26, Heterogeneous Atmospheric Chemistry (D.R. Schryer, ed.), Amer. Geophys. Union, Washington, DC, 167-172 (1982).

P19. Oner, A., Application of Microwave-Induced Emission Spectroscopy to the Study of Gas/Solid Surface Reaction Kinetics, Ph.D. Dissertation, Yale Univ., Chemical Engrg. Dept. (in preparation, 1984).

P20. Rosner, D.E. and Allendorf, H.D., J. Phys. Chem. 75, 308-317 (1971).

P21. Nordine, P.C. and Rosner, D.E., J. Chem. Soc., Faraday Trans. I 72, 1526-1533 (1976).

P22. Nordine, P.C., Rosner, D.E. and Kindlmann, P.J., Rev. Sci. Instrum. 44, 821-826 (1973).

P23. Rosner, D.E. and Allendorf, H.D., J. Phys. Chem. 74, 1829-1839 (1970).

3.2 Verbal Presentations

T1. Rosner, D.E., "Particle and Vapor Mass Transport Through Non-Isothermal Combustion Gases, with Applications to Deposition, Sampling and Surface-Catalyzed Combustion," Eastern States Section-Combustion Inst., Fall '83 Conference, Nov. 8-10, 1983, Brown Univ., Providence, RI.

T2. Sorge, F., Eisner, A.D. and Rosner, D.E., "Deposition of Nonspherical Soot Particles on Cooled Solid Targets," Final Conference, Yale Engrg. and Applied Sci. Summer Research Program, August 18, 1983, New Haven, CT.

T3. Rosner, D.E., "Recent Research on the Laws Governing Vapor and Particle Vapor Deposition from Combustion Gases; Implications for Diminishing Deposition in the Direct Firing of (Beneficiated-) Coal in Combustion Turbines," invited panel discussion; presented at EPRI Conference on Combustion Turbine Systems Modification for Direct (Beneficiated-) Coal Firing, August 3, 1983, Palo Alto, CA.

T4. Rosner, D.E., "Recent Advances in the Field of Vapor and Particle Mass Transfer, with Application to the Fouling of Heat Exchanger Surfaces and Combustion Turbine Blades," Chem. Engrg. Seminar; State Univ. of NY, April 20, 1983, Buffalo, NY.

T5. Rosner, D.E., "Similitude and Correlation Methods in Transport Processes -- Some Instructive Non-Equilibrium Examples," Mech. Engrg. Dept. Colloquium, Ben Gurion Univ., Dec. 26, 1982, Negev, Israel.

T6. Rosner, D.E., "Recent Advances in the Theory of Particle Deposition, with Application to the Fouling of Gas Turbine Blades and Heat Exchanger Surfaces," Aero. Engrg. Dept. Colloquium, Technion-IIT, Dec. 22, 1982, Haifa, Israel.

T7. Rosner, D.E., "Similitude and Correlation Methods in Transport Processes -- Some Instructive Non-Equilibrium Examples," Chem. Engrg. Colloquium, Technion-IIT, Dec. 8, 1982, Haifa, Israel.

T8. Rosner, D.E., "Dynamics of Laminar Condensate Films on Fixed and Rotating Surfaces, with Application to Molten Slag or Salt Films on Combustion Turbine Blades," Fluid Dynamics Research Seminar, Technion-IIT, Dec. 5, 1982, Haifa, Israel.

T9. Rosner, D.E., "Optical Studies of Dew Points and Deposition Rates from Combustion Gases Containing Inorganic Impurities," Aero. Engrg. Dept.-Combustion Research Seminar, Technion-IIT, Nov,. 26, 1982, Haifa, Israel.

T10. Rosner, D.E., Gokoglu, S.A. and Israel, R., "Rational Engineering Correlations of Diffusional and Inertial Particle Deposition Behavior in Non-Isothermal Forced Convection Environments," presented at the Engrg. Foundation Int. Conf. on the Fouling of Heat Exchanger Surfaces, Oct. 30-Nov. 5, 1982, White Haven, PA.

T11. Forbes, K.R., Rosner, D.E. and Gunes, D., "Theory of Deposit Formation on Combustion Turbine Blades," Final Conference, Yale Engrg. and Applied Sci. Summer Research Program, August 19, 1982, New Haven, CT.

T12. Rosner, D.E. and Fernandez de la Mora, J., "Correlation and Prediction of Thermophoretic and Inertial Effects on Particle Deposition Across Non-Isothermal Turbulent Boundary Layers," presented at the ASME-AIAA 1982 Spring Fluids Engrg. Conf., June 7-11, 1982, St. Louis, MO.

4. ADMINISTRATIVE INFORMATION, PERSONNEL

Table 4-1 summarizes the personnel who have contributed to this research program during the period: 12/1/81 - 11/30/83, along with subject matter of each investigator's research contribution. With the exceptions of our summer research assistants (K. Forbes, F. Sorge) and A. Oner, whose work (Section 2.3.2) remains to be prepared for publication, these individuals comprise the PI's co-authors for the papers listed in Section 3.1.

TABLE 4-1

NAME	STATUS @ YALE U.	PRIMARY CONTRIBUTION
ROSNER, D.E.	PI[a], Fac.(ChE)	overall program direction
Anous, N.	GRA[b] (MS program)	condensate layer fluid dynamics
Eisner, A.D.	PDRA	soot-particle deposition rate experiments
Fernandez de la Mora, J.	Fac.(ME)	BL theory of particle transport
Halpern, B.	Fac.(ChE)	chemical and physical energy accommodation
Gokoglu, S.A.	GRA	BL theory of particle transport
Israel, R.	GRA	surface-catalyzed combustion
Kim, S.S.	PDRA[c]	MgO-particle deposition rate experiments
Nagarajan, R.	GRA	condensate layer fluid dynamics
Oner, A.	GRA	microwave-induced plasma emission spectroscopy
Sorge, F.	SRP[d]	soot particle deposition rate experiments

[a] Principal Investigator

[b] Graduate Research Assistant

[c] Postdoctoral Research Assistant

[d] Summer Research Program
Yale Engineering and Applied Science

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2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

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6a. NAME OF PERFORMING ORGANIZATION YALE UNIVERSITY, DEPT. OF CHEMICAL ENGRG., MASON LAB.	6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION AFOSR/NA

6c. ADDRESS (City, State and ZIP Code) 9 HILLHOUSE AVE. NEW HAVEN, CT 06520	7b. ADDRESS (City, State and ZIP Code) BOLLING AFB DC 20332-6448

8a. NAME OF FUNDING/SPONSORING ORGANIZATION AIR FORCE OFFICE OF SCIENTIFIC RESEARCH	8b. OFFICE SYMBOL (If applicable) AFOSR/NA	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F49620-82-K-0020

8c. ADDRESS (City, State and ZIP Code) BLDG. 410 BOLLING AIR FORCE BASE, D.C. 20332	10. SOURCE OF FUNDING NOS.			
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FIELD	GROUP	SUB. GR.	AEROSOLS, CONVECTIVE DIFFUSION, COMBUSTION, DEPOSITION, ENERGY TRANSFER, FOULING, HETEROGENEOUS CATALYSIS, FLOW REACTORS, INERTIAL IMPACTION, OPTICAL METHODS, SOOT,

19. ABSTRACT (Continue on reverse if necessary and identify by block number) (To tal watt Power) (Sq.Cm)

This report summarizes Yale-High Temperature Chemical Reaction Engineering Laboratory methods/results (contract F49620-82-K-0020) for the two-year period ending 11/30/83. Note-worthy findings on interfacial chemical reactions and mass transport include: 1) thermal (Soret) mass transfer can systematically enhance H_2-transport rates to catalytic combustion surfaces by up to 20% in forced convection systems; 2) For submicron particle transport (MgO) to cold surfaces in hot combustion gases thermophoresis causes about a 2000-fold in-crease in the deposition rate (over that expected from convective-(Brownian)diffusion); 3) By accounting for the "suction" and "apparent-source" effects associated with thermo-phoresis within particle laden nonisothermal boundary layers (BLs) simple rational engin-eering correlations have been proposed and verified via numerical laminar and turbulent BL-boundary calculations; 4) Quantitative, rapid-response measurements of solid gasification kinetics have now been made using an adaptation of microwave-induced-plasma emission spec-troscopy. This technique, shown to follow Pt-atom fluxes down to ca. 2×10^{13} atm/cm^2/s,

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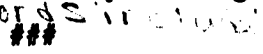**DD FORM 1473, 83 APR** EDITION OF 1 JAN 73 IS OBSOLETE. UNCLASSIFIED

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18. SUBJECT TERMS (CONTINUED)

THERMAL DIFFUSION, THERMOPHORESIS and TURBINE BLADES.

19. ABSTRACT (CONTINUED)

appears to be promising for studying the oxidation kinetics of boron. Originator cusrlied

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